CARPET

1. INTRODUCTION TO WARM AND CARPET

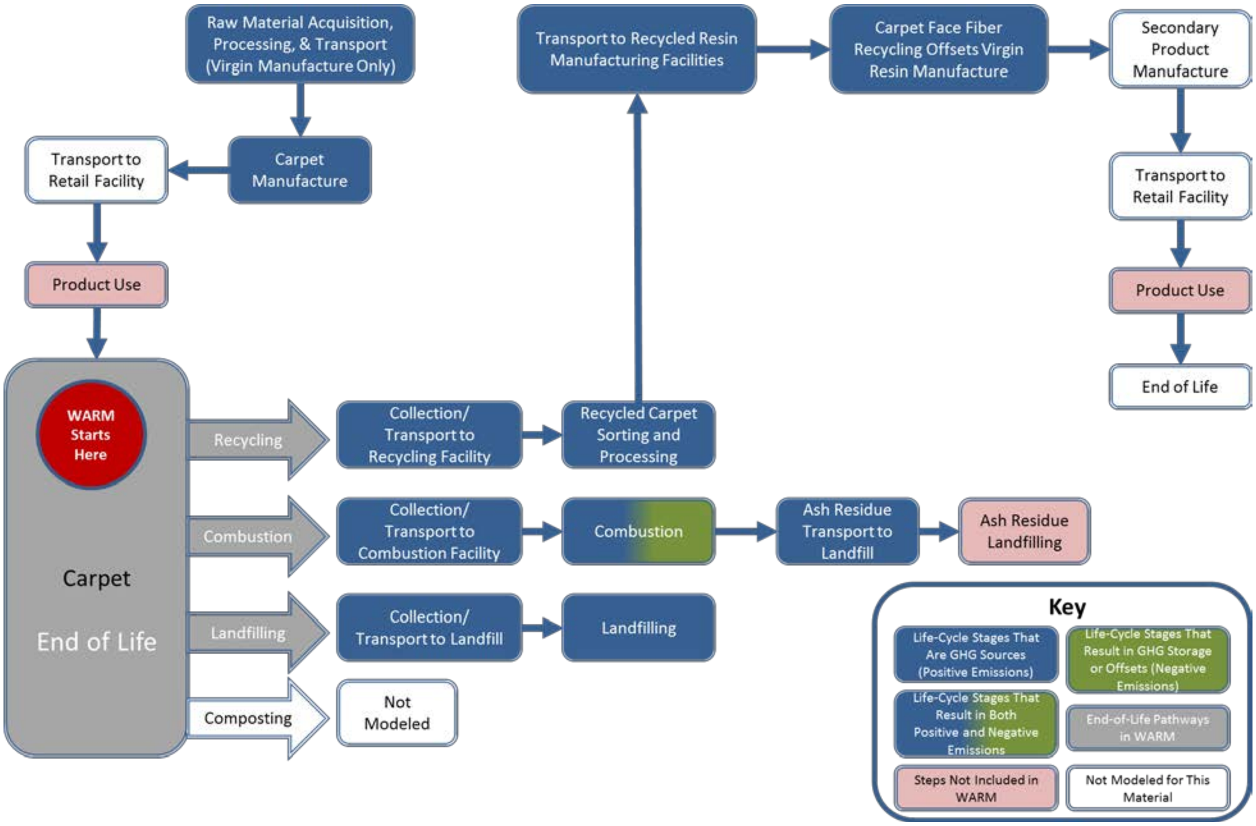
This chapter describes the methodology used in EPA's Waste Reduction Model (WARM) to estimate streamlined life-cycle greenhouse gas (GHG) emission factors for carpet beginning at the point of waste generation. The WARM GHG emission factors are used to compare the net emissions associated with carpet in the following four materials management alternatives: source reduction, recycling, landfilling, and combustion. For background information on the general purpose and function of WARM emission factors, see the Introduction & Overview chapter. For more information on Source Reduction, Recycling, Landfilling, and Combustion, see the chapters devoted to those processes. WARM also allows users to calculate results in terms of energy, rather than GHGs. The energy results are calculated using the same methodology described here but with slight adjustments, as explained in the Energy Impacts chapter.

At the end of its useful life, carpet can be recovered for recycling, sent to a landfill or combusted. Landfilling is the most commonly selected waste management option for carpet. According to EPA (2011), 9 percent of carpet is recycled annually. Efforts by industry, EPA, and other organizations over the past few years have increased the fraction of waste carpet that is recycled.

WARM accounts for the four predominant materials constituting face fibers in residential carpeting: Nylon 6, Nylon 6-6, Polyethylene terephthalate (PET) and Polypropylene (PET). Because the composition of commercial carpet is different than that of residential carpet, the emission factors presented in this chapter and in WARM only apply to broadloom residential carpet. The components of nylon broadloom residential carpet in this analysis include: face fiber, primary and secondary backing and latex used for attaching the backings.

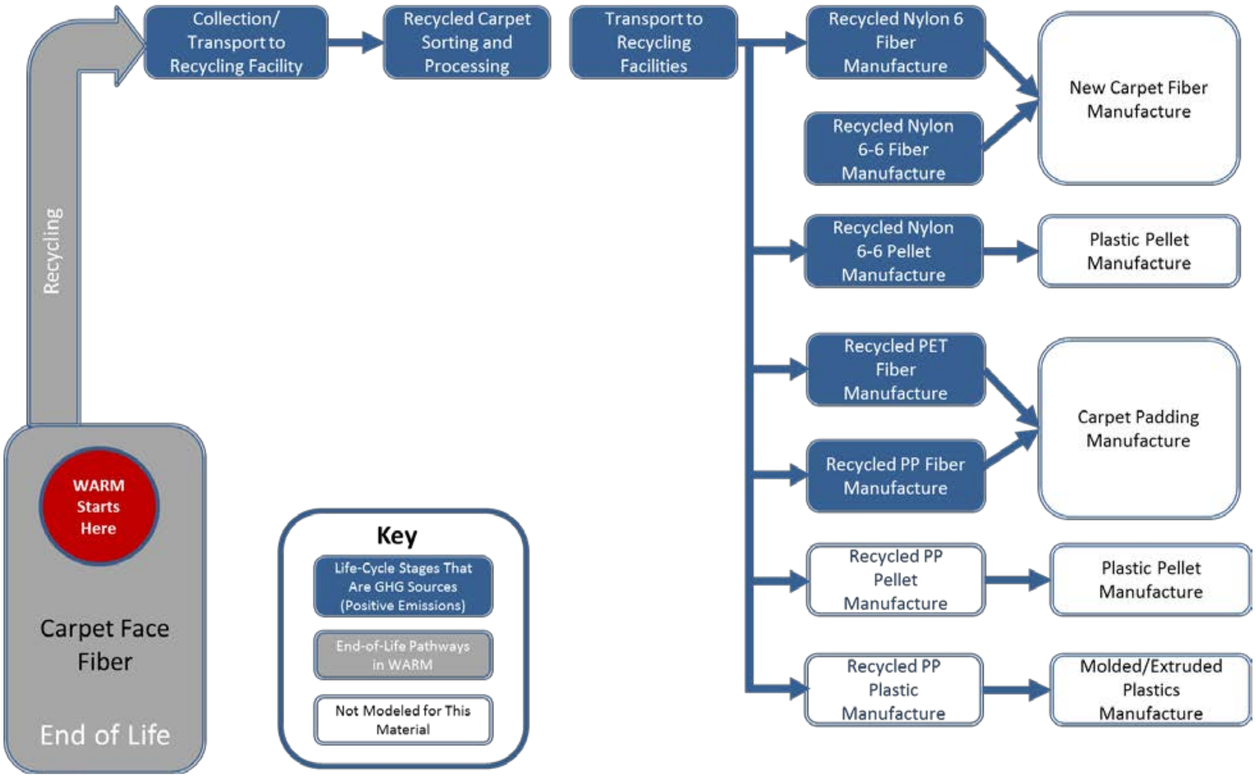
Exhibit 1 shows the general outline of materials management pathways in WARM and how they are modeled for carpet. Recycling carpet is an open-loop process, meaning that components are recycled into secondary materials such as carpet pad, molded products and carpet backing. In WARM, the life-cycle energy and material requirements for converting recycled carpet into these various secondary end products were unavailable (Realff, 2010a). Therefore, in the recycling pathway, the recycling benefits for carpet incorporate the avoided manufacture of the various virgin plastic resins only. Carpet is collected curbside and at special recovery events, or individuals can bring it to designated drop-off sites. Once carpet has been collected for recycling, it is sent to material recovery facilities that specialize in separating and recovering materials from carpet. Building on Exhibit 1, a more detailed flow diagram of the recycling pathway for carpet is provided in Exhibit 2.

Exhibit 1: Life Cycle of Carpet in WARM



Since the original development of the carpet material type energy and GHG emission factors for WARM in 2004, updated life-cycle data for the recycling pathway which more accurately reflect carpet composition and recycling input energyhave become available (Realff, 2011b). The updates include revisions to include two additional types of plastics found in the face fibers of residential broadloom carpets as well as the incorporation of the loss rates within the carpet recycling process . Updated information on the source reduction and landfilling life-cycle pathways for carpet was not available. Therefore, this update to the carpet factors in WARM includes changes only to the recycling and combustion pathways.

Exhibit 2: Detailed Recycling Flows for Carpet in WARM



2. LIFE-CYCLE ASSESSMENT AND EMISSION FACTOR RESULTS

The life-cycle boundaries in WARM start at the point of waste generation, or the moment a material is discarded, and only consider upstream emissions when the production of materials is affected by end-of-life materials management decisions. Recycling and source reduction are the two materials management options that impact the upstream production of materials and consequently are the only management options that include upstream GHG emissions. For more information on evaluating upstream emissions, see the chapters on Recycling and Source Reduction.

WARM includes source reduction, recycling, landfilling, and combustion pathways for materials management of carpet. As Exhibit 3 illustrates, most of the GHG emissions from end-of-life management of carpet occur from waste management of this product, while most of the GHG savings occur from offsetting upstream raw materials acquisition and the manufacturing of other secondary materials that are recovered from carpet.

Exhibit 3: Carpet GHG Sources and Sinks from Relevant Materials Management Pathways

Materials Management Strategies for Carpet	GHG Sources and Sinks Relevant to Carpet		
	Raw Materials Acquisition and Manufacturing	**Changes in Forest or Soil Carbon Storage**	**End-of-Life**
Source Reduction	**Offsets** • Transport of raw materials and intermediate products • Virgin process energy • Virgin process non-energy • Transport of carpet to point of sale	NA	NA
Recycling	**Emissions** • Transport of recycled materials • Recycled process energy • Recycled process non-energy **Offsets** • Emissions from producing Nylon 6, Nylon 6-6, PET and PP plastic resins from virgin material	NA	**Emissions** • Collection of carpet and transportation to recycling center • De-manufacturing and reprocessing recovered carpet
Landfilling	NA	NA	**Emissions** • Transport to landfill • Landfilling machinery
Combustion	NA	NA	**Emissions** • Transport to WTE facility • Combustion-related CO_2 **Offsets** • Avoided electric utility emissions

NA = Not applicable.

WARM analyzes all of the GHG sources and sinks outlined in Exhibit 4 and calculates net GHG emissions per short ton of carpet inputs. For more detailed methodology on emission factors, please see the sections below on individual materials management strategies.

Exhibit 4: Net Emissions for Carpet under Each Materials Management Option ($MTCO_2E$/Short Ton)

Material/Product	Net Source Reduction (Reuse) GHG Emissions For Current Mix of Inputs[a]	Net Recycling Emissions	Net Composting Emissions	Net Landfilling Emissions	Net Combustion Emissions
Carpet	-3.96	-2.37	NA	0.04	1.10

[a] The current mix of inputs for carpet is considered to be 100% virgin material.
Note: Negative values denote net GHG emission reductions or carbon storage from a materials management practice.
NA = Not applicable.

3. RAW MATERIALS ACQUISITION AND MANUFACTURING

The components of nylon broadloom residential carpet in this analysis include: face fiber, primary and secondary backing and latex used for attaching the backings. The face fiber used for nylon carpet is typically made of a combination of Nylon 6, Nylon 6-6, Polyethylene terephthalate (PET) and Polypropylene (PP). For the purpose of developing an emission factor that represents “typical” broadloom residential carpet, WARM reflects the market share of each material in the carpet industry. Carpet backing for broadloom carpet typically consists of polypropylene (PP). For latex used to adhere carpet backings, EPA modeled styrene butadiene, the most common latex used for this purpose. Styrene butadiene latex is commonly compounded with a filler such as calcium carbonate (limestone). Inputs to the manufacture of nylon, PP and styrene butadiene are crude oil and/or natural gas. Exhibit 5 provides the assumed material composition of the typical carpet used for this analysis (FAL, 2002, Realff, 2011b).

Exhibit 5: Material Composition of One Short Ton of Carpet

Material/Product	Application	% of Total Weight	Weight (lbs.) (Assuming 2,000 lbs. of Carpet)
Nylon, PET, PP mix	Face Fiber	45%	910
PP	Woven for backing	15%	304
Styrene butadiene latex	Carpet backing adhesive	8%	164
Limestone	Filler in latex adhesive	32%	648
Total		**100%**	**2,026 lbs.**[a]

[a] Note that these values total 2,026 pounds, which is greater than one short ton. This is because 26 pounds of the raw materials used to manufacture carpet are assumed to be "lost" during the manufacturing process. In other words, producing one short ton of carpet actually requires slightly more than one short ton of raw materials (FAL, 2002).

The main polymers that are used for the face fiber are Nylon 6-6, Nylon 6, PET, and PP with very small amounts of wool and a growing interest in the use of bio-based fibers. The average proportion of each of these plastic resins in carpet face fibers is provided in Exhibit 6. These components are recovered and recycled in different ways, each consuming different amounts of energy. For example, Nylon 6 face fiber is recycled mostly through depolymerization, whereas Nylon 6-6 face fiber is recycled mainly through shaving the fiber followed by remelting and extrusion.

Exhibit 6: Residential Face Fiber Mix 1995-2000

Plastic Resin	% of Total Weight
Nylon 6	40%
Nylon 6-6	25%
PET	15%
PP	20%
Total Face Fiber	**100%**

Source: Realff, 2011b

The process used to turn the components in Exhibit 5 into a finished carpet may include weaving, tufting, needlepunching and/or knitting. According to the Carpet and Rug Institute, 95 percent of carpet produced in the United States is tufted (CRI, 2010). During tufting, face pile yarns are rapidly sewn into a primary backing by a wide multineedled machine. After the face pile yarns are sewn into the primary backing, a layer of latex is used to secure a secondary backing, which adds strength and dimensional stability to the carpet.

4. MATERIALS MANAGEMENT METHODOLOGIES

This analysis considers source reduction, recycling, landfilling, and combustion of carpet. It is important to note that carpet is not recycled into new carpet; instead, it is recycled in an open loop process. The life-cycle assessment of carpet disposal must take into account the variety of second-generation products made from recycled carpet. Information on carpet recycling and the resulting second-generation products is sparse; however, EPA has modeled pathways for which consistent data are available for recycled carpet components. As described previously, due to unavailable life-cycle data on the manufacture of second-generation products from recycled carpet, EPA modeled only the remanufacture of the various virgin plastic resins (i.e., one step before the resins are used to manufacture the second-generation products such as carpet pad, molded products and carpet backing). Please see Exhibit 2 for the process flow diagram that illustrates these boundaries.

The data source used to develop the emissions factor for source reduction is a 2002 report published by Franklin Associates Limited (FAL) on energy and GHG emission factors for the manufacture and end-of-life management of carpet (FAL, 2002). These data were based on a number of industry and academic data sources dating from the 1990s and 2000s. The background data for the development of the source reduction carpet emission factors are available in an EPA background document associated with the FAL 2002 report (EPA, 2003). The data source used to develop the open-loop recycling emission factor for carpet is based on updated data from Dr. Matthew Realff of Georgia Institute of Technology (Georgia Tech). His findings were informed by the 2009 Carpet America Recovery Effort (CARE) 2009 annual report, which provided a breakdown of the components of carpet face fiber polymer (CARE, 2009). In 2011, Dr. Realff collected data in collaboration with the carpet industry that provided the energy inputs used to recycle carpet face fiber into plastic constituents (Realff, 2011b). Dr. Realff provided the life-cycle data for recycling carpet in a spreadsheet designed for incorporation into WARM (Realff, 2011c).

4.1 SOURCE REDUCTION

Source reduction activities reduce the amount of carpet that is produced, thereby reducing GHG emissions from carpet production. Source reduction of carpet can be achieved through using less carpeting material per square foot (i.e., thinner carpet) or by finding a way to make existing carpet last longer through cleaning or repair. For more information on this practice, see the Source Reduction chapter.

Exhibit 7 outlines the GHG emission factor for source reducing carpet. GHG benefits of source reduction are calculated as the avoided emissions from raw materials acquisition and manufacturing (RMAM) of new carpet.

Exhibit 7: Source Reduction Emission Factor for Carpet ($MTCO_2E$/Short Ton)

Material/ Product	Raw Material Acquisition and Manufacturing for Current Mix of Inputs	Raw Material Acquisition and Manufacturing for 100% Virgin Inputs	Forest Carbon Storage for Current Mix of Inputs	Forest Carbon Storage for 100% Virgin Inputs	Net Emissions for Current Mix of Inputs	Net Emissions for 100% Virgin Inputs
Carpet	-3.96	-3.96	NA	NA	-3.96	-3.96

Note: Negative values denote net GHG emission reductions or carbon storage from a materials management practice. Information on the share of recycled inputs used in production is unavailable or is not a common practice; EPA assumes that the current mix is comprised of 100% virgin inputs. Consequently, the source reduction benefits of both the “current mix of inputs” and “100% virgin inputs” are the same.
NA = Not applicable.

Post-consumer emissions are the emissions associated with materials management pathways that could occur at end-of-life. Source reducing carpet does not involve post-consumer emissions because production of the material is avoided in the first place.Forest products are not used in the production of carpet; therefore, forest carbon storage is not applicable to carpet and thus does not contribute to the source reduction emission factor.

4.1.1 Developing the Emission Factor for Source Reduction of Carpet

To calculate the avoided GHG emissions for carpet, EPA looks at three components of GHG emissions from RMAM activities: process energy, transportation energy and process non-energy GHG emissions. Exhibit 8 shows the results for each component and the total GHG emission factor for source reduction. More information on each component making up the final emission factor is provided in the remainder of this section.

Exhibit 8: Raw Material Acquisition and Manufacturing Emission Factor for Virgin Production of Carpet ($MTCO_2E$/Short Ton)

(a) Material/Product	(b) Process Energy	(c) Transportation Energy	(d) Process Non-Energy	(e) Net Emissions (e = b + c + d)
Carpet	3.35	0.10	0.51	3.96

FAL (2002) reports the amount of energy required to produce one short ton of carpet as 60.32 million Btu. FAL (2002) also provided the fuel mix that makes up this energy estimate. To estimate GHG emissions, EPA multiplied the fuel consumption (in Btu) by the fuel-specific carbon contents. Summing the resulting GHG emissions, by fuel type, gives the total process energy GHG emissions, including both CO_2 and CH_4, from all fuel types used in carpet manufacture (Exhibit 9).

Exhibit 9: Process Energy GHG Emissions Calculations for Virgin Production of Carpet

Material/Product	Process Energy per Short Ton Made from Virgin Inputs (Million Btu)	Process Energy GHG Emissions ($MTCO_2E$/Short Ton)
Carpet	60.32	3.35

Transportation energy emissions come from fossil fuels used to transport carpet raw materials and intermediate products. The methodology for estimating these emissions is the same as that for process energy emissions. Based upon estimated total carpet transportation energy in Btu, EPA calculates the total emissions using fuel-specific carbon coefficients (Exhibit 10).

Exhibit 10: Transportation Energy Emissions Calculations for Virgin Production of Carpet

Material/Product	Transportation Energy per Short Ton Made from Virgin Inputs (Million Btu)	Transportation Energy GHG Emissions ($MTCO_2E$/Short Ton)
Carpet	1.36	0.10

Note: The transportation energy and emissions in this exhibit do not include retail transportation.

Process non-energy GHG emissions occur during manufacture but are not related to combusting fuel for energy. For carpet, non-energy GHGs are emitted in the use of solvents or chemical treatments. FAL provided data on GHG emissions from non-energy-related processes in units of pounds of native gas (2002). We convert pounds of gas per 1,000 lbs of carpet to metric tons of gas per short ton of carpet and then multiply that by the ratio of carbon to gas to produce the emission factor in $MTCO_2E$ per short ton of carpet, as detailed in the example below, showing the calculation of CH_4 process non-energy emissions for carpet. Exhibit 11 shows the components for estimating process non-energy GHG emissions for carpet.

2.72 lbs CH_4/1,000 lbs carpet × 2,000 lbs carpet/1 short ton carpet × 1 metric ton CH_4/2,205 lbs CH_4 = 0.0025 MT CH_4/short ton carpet

0.0025 MT CH_4/short ton carpet × 21 MTCO2E/metric ton CH_4 = 0.05 $MTCO_2E$/short ton carpet

Exhibit 11: Process Non-Energy Emissions Calculations for Virgin Production of Carpet

Material/Product	CO_2 Emissions (MT/Short Ton)	CH_4 Emissions (MT/Short Ton)	CF_4 Emissions (MT/Short Ton)	C_2F_6 Emissions (MT/Short Ton)	N_2O Emissions (MT/Short Ton)	Non-Energy Carbon Emissions ($MTCO_2E$/Short Ton)
Carpet	0.01	<0.01	–	–	<0.01	0.51

– = Zero emissions.

4.2 RECYCLING

This section describes the development of the recycling emission factor, which is shown in the final column of Exhibit 12. For more information on recycling in general, please see the Recycling chapter. As mentioned previously, updated life-cycle data for recycling carpet were available from Dr. Matthew Realff of Georgia Tech. His findings were informed by the 2009 Carpet America Recovery Effort (CARE) 2009 annual report, which provided a breakdown of the components of carpet face fiber polymers in conjunction with the collaboration with the carpet industry to collect data that provided the energy inputs used to recycle carpet face fiber plastic constituents.

Exhibit 12: Recycling Emission Factor for Carpet ($MTCO_2E$/Short Ton)

Material/ Product	Raw Material Acquisition and Manufacturing (Current Mix of Inputs)	Materials Management Emissions	Recycled Input Credit[a] Process Energy	Recycled Input Credit[a] – Transportation Energy	Recycled Input Credit[a] – Process Non-Energy	Forest Carbon Sequest-ration	Net Emissions (Post-Consumer)
Carpet	NA	NA	-1.39	0.01	-0.96	NA	-2.37

[a] Includes emissions from the virgin production of secondary materials.
Note: Negative values denote net GHG emission reductions or carbon storage from a materials management practice.
NA = Not applicable.

In WARM, EPA models open-loop recycling of carpet into a mixture of following plastic resins: Nylon 6, Nylon 6-6, PET and PP. The resulting plastic resins produced from the open-loop recycling process will then be converted into a number of products including new carpet fiber, molded or extruded plastics and plastic pellets. The additional energy and resultant GHG emissions from the conversion of the recycled plastic resins into these final secondary products were not available. Therefore, the recycling benefits for carpet are limited to the avoided energy and GHG emissions associated with virgin plastic resin manufacture.

The recycled input credits shown in Exhibit 12 include all of the GHG emissions associated with collecting, transporting, processing and recycling or remanufacturing carpet into secondary materials. None of the upstream GHG emissions from manufacturing the carpet in the first place are included; instead, WARM calculates a "recycled input credit" by assuming that the recycled material avoids—or offsets—the GHG emissions associated with producing the same amount of secondary resins from virgin inputs. The eventual secondary products those resins are then used to manufacture are not factored into WARM's calculations. Consequently, GHG emissions associated with management (i.e., collection, transportation and processing) of end-of-life carpet are included in the recycling credit calculation. Since carpet does not contain any wood products, there are no recycling benefits associated with forest carbon storage. The GHG benefits from the recycled input credits are discussed further below.

EPA calculates the GHG benefits of recycling carpet by comparing the difference between the emissions associated with manufacturing a short ton of each of the four resins derived from recycled carpet and the emissions from manufacturing the same ton from virgin materials, after accounting for losses that occur in the recycling process. WARM assumes that both recycled Nylon 6-6 fiber and Nylon 6-6 pellets displace the virgin production of Nylon 6-6 resin. These results are then weighted by the distribution shown in Exhibit 13 to obtain a composite emission factor for recycling one short ton of carpet. This recycled input credit is composed of GHG emissions from process energy, transportation energy and process non-energy.

Exhibit 13: Secondary Resins Produced from Recycled Carpet Fibers

Material/Product	Percent of Recovered Carpet Face Fiber
Nylon 6 Fiber	54.02%
Nylon 6-6 Fiber	6.72%
Nylon 6-6 Pellet	23.07%
PET Fiber	7.71%
PP Fiber	8.62%

Source: Realff, 2011b

To calculate each component of the recycling emission factor, EPA follows five steps, which are described in detail below.

Step 1. *Calculate emissions from virgin production of one short ton of secondary resin.*

We apply fuel-specific carbon coefficients to the life-cycle data for virgin RMAM of each secondary resin (FAL, 2010, Plastics Europe, 2005). The life-cycle data for virgin production of Nylon 6 and Nylon 6-6 were unavailable for production of these resins in the United States. Thus, life-cycle data for the production of these resins in the European context were used as a proxy (Plastics Europe, 2005). Life-cycle data for the production of PET and PP resins are the same as used in the development of the PET and PP emission factors in WARM (FAL, 2011). The upstream life-cycle data also incorporate transportation and process non-energy data. The calculations for virgin process, transportation and process non-energy emissions for the secondary resins are presented in Exhibit 14, Exhibit 15, and Exhibit 16, respectively.

Exhibit 14: Process Energy GHG Emissions Calculations for Virgin Production of Carpet Secondary Resins

Material/Product	Process Energy per Short Ton Made from Virgin Inputs (Million Btu)	Energy Emissions ($MTCO_2E$/Short Ton Carpet)
Nylon 6	112.16	6.60
Nylon 6-6	122.40	7.45
PET	26.65	1.68
PP	23.69	1.14

Exhibit 15: Transportation Energy Emissions Calculations for Virgin Production of Carpet Secondary Resins

Material/Product	Transportation Energy per Short Ton Made from Virgin Inputs (Million Btu)	Transportation Emissions ($MTCO_2E$/Short Ton Carpet)
Nylon 6	1.05	0.07
Nylon 6-6	0.82	0.05
PET	1.70	0.07
PP	2.36	0.13

Exhibit 16: Process Non-Energy Emissions Calculations for Virgin Production of Carpet Secondary Resins

Material/Product	CO_2 Emissions (MT/Short Ton Carpet)	CH_4 Emissions (MT/Short Ton Carpet)	CF_4 Emissions (MT/Short Ton Carpet)	C_2F_6 Emissions (MT/Short Ton Carpet)	N_2O Emissions (MT/Short Ton Carpet)	Non-Energy Carbon Emissions ($MTCO_2E$/Short Ton)
Nylon 6	1.04	2.25E-03	–	–	0.01	3.51
Nylon 6-6	0.84	2.02E-03	–	–	6.62E-04	1.08
PET	0.27	4.76E-03	–	–	–	0.37
PP	0.07	0.01	–	–	4.08E-06	0.19

– = Zero emissions.

Step 2. *Calculate emissions from recycled production of one short ton of the secondary resin.*

EPA then applies the same carbon coefficients to the energy data for the production of the secondary resin production from recycled carpet. Personal correspondence with Dr. Matthew Realff (2011a) indicated that no non-energy process emissions occur in recycled production of secondary resins from carpet. Exhibit 17 and Exhibit 18 present the emission calculation components for recycled secondary product process energy emissions and transportation energy emissions, respectively.

Exhibit 17: Process Energy GHG Emissions Calculations for Recycled Production of Carpet Secondary Resins

Material/Product	Process Energy per Short Ton Made from Recycled Inputs (Million Btu)	Energy Emissions ($MTCO_2E$/Short Ton)
Nylon 6 Fiber	74.24	3.96
Nylon 6-6 Fiber	3.13	0.18
Nylon 6-6 Pellet	13.39	0.74
PET Fiber	1.24	0.07
PP Fiber	10.55	0.58

Exhibit 18: Transportation Energy GHG Emissions Calculations for Recycled Production of Carpet Secondary Resins

Material/Product	Transportation Energy per Short Ton Made from Recycled Inputs (Million Btu)	Transportation Emissions ($MTCO_2E$/Short Ton)
Nylon 6 Fiber	0.85	0.06
Nylon 6-6 Fiber	2.56	0.19
Nylon 6-6 Pellet	3.67	0.00
PET Fiber	3.24	0.00
PP Fiber	0.84	0.00

Note: The transportation energy and emissions in this exhibit do not include retail transportation.

Step 3. *Calculate the difference in emissions between virgin and recycled production.*

To calculate the GHG reductions associated with replacing virgin production with recycled production of secondary products, we then subtract the emissions from recycled production (Step 2) from the emissions from virgin production (Step 1). These results are shown in Exhibit 19.

Exhibit 19: Differences in Emissions between Recycled and Virgin Carpet Manufacture ($MTCO_2E$/Short Ton)

	Product Manufacture Using 100% Virgin Inputs ($MTCO_2E$/Short Ton)			Product Manufacture Using 100% Recycled Inputs ($MTCO_2E$/Short Ton)			Difference Between Virgin and Recycled Manufacture ($MTCO_2E$/Short Ton)		
Material/Product	Process Energy	Transport-ation Energy	Process Non-Energy	Process Energy	Transporta-tion Energy	Process Non-Energy	Process Energy	Transpor-tation Energy	Process Non-Energy
Nylon 6 Fiber	6.60	0.07	3.51	3.96	0.06	–	-2.63	-0.01	-3.51
Nylon 6-6 Fiber	7.45	0.05	1.08	0.18	0.19	–	-7.27	0.13	-1.08
Nylon 6-6 Pellet	7.45	0.05	1.08	0.74	0.003	–	-6.71	-0.05	-1.08
PET Fiber	1.68	0.07	0.37	0.07	0.002	–	-1.61	-0.07	-0.37
PP Fiber	1.14	0.13	0.19	0.58	0.001	–	-0.56	-0.13	-0.19

Note: Negative values denote net GHG emission reductions or carbon storage from a materials management practice.
– = Zero emissions

Step 4. *Adjust the emissions differences to account for recycling losses.*

For almost every material that gets recycled, some portion of the recovered material is unsuitable for use as a recycled input. This portion is discarded either in the recovery stage or in the manufacturing stage. Consequently, less than one ton of new material is typically made from one ton of recovered materials. Material losses are quantified and translated into loss rates. Exhibit 20 shows the relative amounts of each plastic resin recovered from a given ton of recycled carpet and their end uses. Associated with each of these end uses are different recycling routes. For example Nylon 6 face fiber is recycled mostly through depolymerization, whereas Nylon 6-6 face fiber is recycled mainly through shaving the fiber followed by remelting and extrusion.

The distribution of end uses for carpet material is shown in Exhibit 20 and illustrates the total amount of plastic resins recovered and ultimately remanufactured per 1000 kg of recycled carpet. Note that the recovery and remanufacture of plastic resins per 1000 kg of incoming carpet material is less than 50 percent by mass indicating a high loss rate for recycling carpet. Furthermore, due to lack of data, EPA did not factor in the recovery of plastic pellets and molded plastics made from recovered PP resin. Exhibit 21 shows the recovery rates for each plastic resin recovered from carpet face fiber. The recovery rates add up to less than 100 percent due to the low overall recovery rate outlined in Exhibit 20.

Exhibit 20: End uses for recycled carpet based on 1000 kg of incoming carpet material

	Per 1000 kg Recycled Carpet				
Material/Product	**Total**	**Nylon 6**	**Nylon 6-6**	**PET**	**PP**
New Carpet	233.3	207.5	25.8	–	–-
Plastic Pellets	171.1	–	88.6	–	82.5*
Molded or Extruded Plastics	25.9	–	–	–	25.9*
Carpet Padding	62.2	–	–	29.6	33.1
Total Polymer Weight	**492.5**	**207.5**	**114.4**	**29.6**	**141.5**

Note: The recycled flows indicated by an asterisk (*) are not accounted in the recycling pathway in WARM because the life-cycle data associated with recovering these flows in the recycling process were not available.
Source: Realff, 2011b

Each product's process energy, transportation energy and process non-energy emissions are weighted by the percentages in Exhibit 21 and then they are summed as shown in the final column of Exhibit 22.

Exhibit 21: Calculation of Adjusted GHG Savings for Carpet Recycled into Secondary Products

Material/Product	Rate of Recovery per Short Ton Carpet Collected
Nylon 6 Fiber	20.7%
Nylon 6-6 Fiber	2.58%
Nylon 6-6 Pellet	8.85%
PET Fiber	2.96%
PP Fiber	3.31%

Source: The WARM Model – Analysis and Suggested Action (Realff, 2011b).

Step 5. *Weight the results by the percentage of recycled carpet that the secondary products comprise.*

Exhibit 22: Carpet Recycling Emission Factors ($MTCO_2E$/Short Ton)

Material/Product	Recycled Input Credit for Recycling One Short Ton of Carpet			
	Weighted Process Energy ($MTCO_2E$/Short Ton Product)	Weighted Transport Energy ($MTCO_2E$/Short Ton Product)	Weighted Process Non-Energy ($MTCO_2E$/Short Ton Product)	Total ($MTCO_2E$/Short Ton Product)
Nylon 6 Fiber	-0.55	-0.002	-0.82	-1.37
Nylon 6-6 Fiber	-0.19	0.003	-0.03	-0.21
Nylon 6-6 Pellet	-0.59	-0.005	-0.10	-0.69
PET Fiber	-0.05	-0.002	-0.01	-0.06
PP Fiber	-0.02	-0.004	-0.01	-0.03
Carpet Total	**-1.39**	**-0.01**	**-0.96**	**-2.36**

Note: Negative values denote net GHG emission reductions or carbon storage from a materials management practice.

4.3 COMPOSTING

Carpet is not subject to aerobic bacterial degradation and therefore cannot be composted. As a result, WARM does not consider GHG emissions or storage associated with composting carpet.

4.4 COMBUSTION

Combustion results in both direct and indirect emissions: direct emissions from the combustion process itself and indirect emissions associated with transportation to the combustor. To the extent that carpet combusted at waste-to-energy (WTE) facilities produces electricity, combustion offsets GHG emissions that would have otherwise been produced from non-baseload power plants feeding into the national electricity grid. These components make up the combustion factor calculated for carpet. The tables presented here are based on the national average grid mix, rather than on any of the regional grid mixes also available in the Excel version of WARM.

For further information on combustion, see the Combustion chapter. Because WARM's analysis begins with materials at end-of-life, emissions from RMAM are zero. Exhibit 23 shows the components of the emission factor for combustion of carpet. Further discussion on the development of each piece of the emission factor is discussed below.

Exhibit 23: Components of the Combustion Net Emission Factor for Carpet ($MTCO_2E$/Short Ton)

Raw Material Acquisition and Manufacturing (Current Mix of Inputs)	Transportation to Combustion	CO_2 from Combustion	N_2O from Combustion	Avoided Utility Emissions	Steel Recovery	Net Emissions (Post-Consumer)
–	0.03	1.67	–	-0.59	–	1.10

Note: Negative values denote net GHG emission reductions or carbon storage from a materials management practice.

4.4.1 Developing the Emission Factor for Combustion of Carpet

EPA estimates that carpet has a weighted carbon content of 51 percent and that 98 percent of that carbon is converted to CO_2 during combustion. These estimates are based on the carbon that is contained within the various plastics and the limestone in carpet. These carbon contents and resulting direct CO_2 emissions from combustion of carbon in carpet are presented in Exhibit 24.

Exhibit 24: Carpet Combustion Emission Factor Calculation

Components	% of Total Weight	Carbon Content	Carbon Content % of Total Weight	Carbon Converted to CO_2 during Combustion	Total $MTCO_2E$/Short Ton
Styrene-butadiene (latex)	10%	90%	9%	98%	0.29
Limestone	37%	12%	4%	98%	0.13
Backing Fiber (PET)	11%	86%	9%	98%	0.29
Face Fibers:					
Nylon 6 and Nylon 6-6	28%	64%	18%	98%	0.59
PP	8%	86%	7%	98%	0.23
PET	6%	63%	4%	98%	0.13
Carpet (Sum)	**NA**	**NA**	**51%**	**98%**	**1.67**

Sources: Styrene-butadiene carbon content calculated from chemical formula; limestone carbon content (Kantamaneni, 2002); polypropylene and nylon carbon contents (EPA, 2001, Ch. 7). Face fiber plastic component distribution from personal communication with Matthew Realff (Realff 2011a).
Totals may not sum due to independent rounding.
NA = Not applicable.

EPA estimates CO_2 emissions from transporting carpet to the WTE plant and transporting ash from the WTE plant to the landfill using data provided by FAL (2002). Transportation-related CO_2 emissions were estimated to be 0.03 $MTCO_2E$ per short ton of carpet combusted.

Most utility power plants use fossil fuels to produce electricity, and the electricity produced at a WTE plant reduces the demand for fossil-derived electricity. As a result, the combustion emission factor for carpet includes avoided GHG emissions from utilities. We calculate the avoided utility CO_2 emissions based on the energy content of carpet, the combustion efficiency of the WTE plant including transmission and distribution losses, and the national average carbon-intensity of electricity produced by non-baseload power plants. EPA utilized the energy content from recent analysis, which presents the energy content that is more representative of the current carpet composition (Realff, 2010b).

Exhibit 25 shows the estimated utility offset from combustion of carpet.

Exhibit 25: Utility GHG Emissions Offset from Combustion of Carpet

(a) Material/Product	(b) Energy Content (Million Btu per Short Ton)	(c) Combustion System Efficiency (%)	(d) Emission Factor for Utility-Generated Electricity ($MTCO_2E$/ Million Btu of Electricity Delivered)	(e) Avoided Utility GHG per Short Ton Combusted ($MTCO_2E$/Short Ton) (e = b × c × d)
Carpet	15.2*	17.8%	0.22	1.10

* Calculated from the "Carpet 1" architecture in Table 2 of Realff 2010b using the heat of combustion (20% solid) value

4.5 LANDFILLING

Typically, the emission factor for landfilling is composed of four parts: landfill CH_4; CO_2 emissions from transportation and landfill equipment; landfill carbon storage; and avoided electric utility emissions. However, as with other non-biodegradable materials in WARM, there are zero landfill methane emissions, landfill carbon storage or avoided utility emissions associated with landfilling carpet, as shown in Exhibit 26. GHG emissions associated with RMAM are not included in WARM's landfilling emission factors. As a result, the emission factor for landfilling carpet represents only the transportation emissions associated with collecting the waste and operating the landfill equipment. For more information on landfilling, refer to the Landfilling chapter.

Exhibit 26: Landfilling Emission Factor for Carpet ($MTCO_2E$/Short Ton)

Raw Material Acquisition and Manufacturing (Current Mix of Inputs)	Transportation to Landfill	Landfill CH_4	Avoided CO_2 Emissions from Energy Recovery	Landfill Carbon Storage	Net Emissions (Post-Consumer)
–	0.04	NA	NA	NA	0.04

NA = Not applicable.
– = Zero emissions.

5. LIMITATIONS

As outlined in the Recycling section (4.2), the open-loop recycling process is a complicated end-of-life process for carpet. There are some limitations associated with modeling the GHG emissions from open-loop carpet recycling, including limited availability of representative life-cycle inventory (LCI) data for carpet and the materials recovered from them.

Given the complex open-loop recycling process and a lack of more complete information on carpet recycling, the recycling factor for carpet is subject to important limitations. A primary data gap is the availability of representative LCI data for carpet in the closed-loop recycling process, and the materials recovered from them in the open-loop recycling process. For this analysis, we use life-cycle data to represent the recovery of various plastic resins from recycled carpet but do not incorporate the additional energy and material requirements for converting these plastic resins into secondary products. Since the WARM carpet emission factor was initially developed, manufacturers have increased their capacity to recycle carpet into different end products including new carpet, plastic pellets, molded plastics and carpet padding. According to the CARE Annual Report for 2009, 47 percent of carpet recovered for recycling is used to manufacture new carpet, 35 percent was used to manufacture plastic pellets, 13 percent was used to manufacture carpet padding, and 5 percent was used to manufacture molded or extruded plastics (CARE, 2009). Updated LCI data on the conversion of plastic resins into final secondary products for carpet could have important effects on our results for the recycling benefits associated with carpet. EPA is investigating the availability of data necessary to develop a more representative open-loop recycling emission factor for carpet.

Finally, the open-loop recycling pathways for each carpet type vary significantly (Realff, 2010a). WARM currently assumes that the same average mix of carpet types is recycled by each of the three open-loop recycling pathways, since at the time the emission factors were created, no further information was available. However, more recent data show that some carpet types are rarely or never recycled into some open-loop products. For example, Nylon 6 carpet is exclusively recycled into new Nylon 6 carpet, PET carpet is exclusively recycled into new carpet padding, and Nylon 6-6 carpet is only recycled into new Nylon 6-6 carpet and plastic pellets (CARE, 2009).

Emissions associated with retail transport of carpet from manufacturing to point of sale were not developed in the original WARM analysis as the representative transportation mode/distance data were not available. EPA is investigating the availability of these data through the U.S. Census and will likely incorporate emissions from retail transport in the next version of the carpet emission factor in WARM.

For the source reduction pathway, the LCI data to estimate GHG emissions from the manufacture of carpet from virgin materials are slightly outdated. EPA is investigating the availability of updated life-cycle data and will revise the source reduction emission factor accordingly in WARM.

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